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LA-UR -89-1905

CONF-890605--55

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SUBMITTED TO IEEE - Pulsed Power
Monterey, CA
June 12-14/89

Los Alamos

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FORM NO 836 R4
ST NO 2629 5/81

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CALCULATIONAL EVALUATION OF PLASMA FLOW SWITCHES FOR THE LOS ALAMOS FOIL IMPLOSION PROJECT*

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ABSTRACT

The next system design under consideration for the Los Alamos Foil Implosion Project (Trailmaster) is projected to deliver in excess of 15 MA of electrical current produced by high-explosive driven flux compression generators to a foil load. A plasma flow switch is being investigated as the final pulse shaping step in this system. The performance of these switches is being evaluated using a wide variety of computational tools including zero-, one- and two-dimensional MHD codes and a 3-D view-factor radiation transport code. We are concerned with the effects of radiation from the switch plasma prior to switching current to the load, and the interaction of the switch plasma on existing perturbations and as a source of perturbation on the imploding load.

I. Introduction

Researchers at Air Force Weapons Laboratory (AFWL) have reported considerable success in efficiently transferring current to an imploding liner using a plasma flow switch.[1] In the Los Alamos foil implosion project, Trailmaster, we are interested in this approach for several reasons. Our use of explosively driven magnetic flux compression generators, while providing an inexpensive source of high current, has led to a considerable pulse shaping problem. The plasma flow switch has proven more efficient in transferring current than other closing switch options. In addition, the plasma flow switch protects the load region from high voltages generated by an opening switch until the current is large enough to provide magnetic insulation.

In the Trailmaster project we anticipate using plasma flow switches at higher current levels than have been switched heretofore. We are, therefore, using a variety of computational tools to evaluate switch designs for the Trailmaster project. We are conducting simulations with a 0-D, horizontal, slug model to find the optimum plasma mass and flow channel parameters. Our 1-D, Lagrangian, code, RAVEN, will run in planar geometry. It is being used to provide a variety of benchmarking calculations, radiation flux for ablation studies, and initial conditions for our 2-D, Eulerian, calculations. Our 3-D view factor and radiation transport code, GOPHER is being used, in conjunction with RAVEN, to examine the effects of radiation from the flowing plasma. Finally, we are in the process of making 2-D, Eulerian, calculations to evaluate the effects of the flowing switch plasma on the quality of the liner implosion.

II. Zero-Dimensional Modeling

Our 0-D, horizontal, slug model is included in the electrical circuit package in the RAVEN code. We have benchmarked the model by comparing to 1-D, planar geometry, calculations with RAVEN. As an example of our use of this model, the 1.5 mJ, Pegasus capacitor bank[2] is embarking on a series of plasma flow switch experiments to assist in designing such a switch for Trailmaster. We have used the 0-D model to determine the optimal mass for this study such that the switching plasma will be over the load region, 6.5 cm down the channel, at the peak of the bank's quarter cycle. This quarter cycle period is, of course, a function of the time dependent inductance of the switch itself. Figure 1 shows the 0-D model's predictions for current and plasma position for a 35 mg plasma. This would be approximately 30% of the mass in the switches fielded by AFWL.

III. One-Dimensional MHD and Radiation Ablation Calculations

We are using RAVEN, 1-D, in planar geometry, to benchmark the 0-D model, provide radiation flux estimates, and initial conditions for 2-D, Eulerian, calculations. The radiation induced ablation calculations start with the calculated flux output from RAVEN and view factor values from the GOPHER code. These values are convolved and the resultant flux is imposed on the outer most zone of an exposed surface in a RAVEN calculation. In making these ablation studies we were concerned that the interaction of the aluminum plasma in the switch and the plastic barrier foil might lead to higher temperatures than would be predicted by a pure aluminum calculation. We have, therefore, carried out comparison calculations with pure aluminum and aluminum plus a barrier foil.

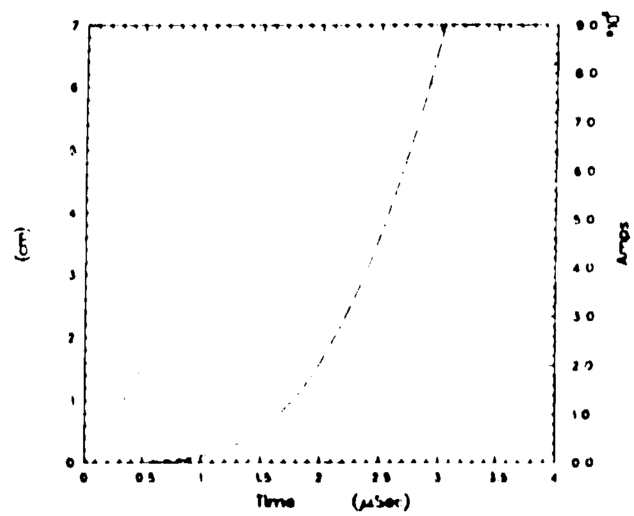

Fig. 1. Slug model prediction for the position of the switch plasma (dash-dot line, left axis), and current from the Pegasus capacitor bank for a plasma mass of 35 mg.

*Work performed under the auspices of the University of California for the US Department of Energy under contract number W-7405-ENG-36.

In these comparison calculations we have used Pegasus capacitor bank parameters but AFWL mass values. In running RAVEN in planar geometry we approximate the cylindrical shape of the channel as a rectangle with width equal to the circumference of the center of the channel and height equal to the separation of the electrodes. In this calculation we have used a polyurethane equation-of-state from the SESAME tables and not allowed it to become conductive. The wire array is approximated by an aluminum foil with the correct mass.

The positions of the Lagrangian zones as functions of time for both calculations are shown in Fig. 2. Note that in both calculations the upstream (back) zones of the aluminum (in the direction of the capacitor bank and at higher values of Z) blow off but are caught by the $J \times B$ force and collide back with the main body of the plasma in the 1.5 to 2 μs time frame. The exact time is dependent on the zoning resolution which is finer on the back of the plasma in the aluminum only calculation. The collision between the aluminum plasma and barrier foil starts at 1.1 μs but its effects are not felt on the back of the plasma until well after the 2 μs point. The temperatures of the zones in both calculations are shown in Fig. 3. The highest values are for those zones on the back of the plasma, where the current is being carried. The actual values are quite similar between the two calculations. The barrier foil does, however, clearly reduce the spread in the total plasma. In comparing the results shown in Figs. 2 and 3 we have concluded that for most purposes calculating with aluminum only (no barrier foil) for the switch plasma is sufficient.

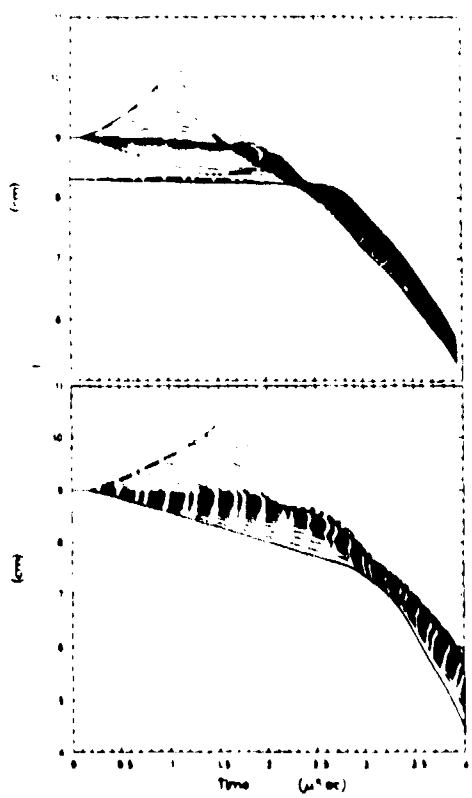

Fig. 2. Calculated positions as functions of time for the Lagrangian zones with (top) and without (bottom) a separate, polyurethane, barrier foil. Total mass is the same in each calculation, absolute positions have no significance.

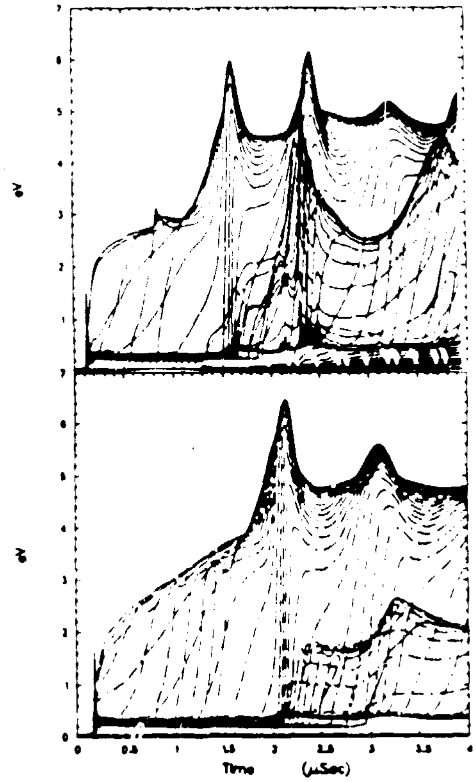

Fig. 3. Calculated temperatures for the Lagrangian zones with (top) and without (bottom) a separate, polyurethane, barrier foil.

One possible future system in the Trailmaster project would combine a Mark IX generator,[3] an explosively formed fuse in a flux-conserving geometry,[4] and a plasma flow switch. As a preliminary test for such a system, a dynamic load, similar to a plasma flow switch, has been designed. A blueprint of this load is shown in Fig. 4.

We have used the RAVEN code to estimate the performance of such a system. It predicts that the current in the dynamic load will reach approximately 16 MA in 2.3 μs if the mass of the plasma is the same as that used in the AFWL experiments. The highest temperatures are on the "back" of the plasma, the generator side. This temperature reaches 8 eV during the initial shock when the $J \times B$ force overcomes the expansion of the plasma and drives the back zones of the plasma into the main body of the plasma. During most of the calculation this temperature is closer to 6 eV. We are concerned that the radiation from this 6–8 eV plasma might lead to radiation induced ablative channel closure.

We have used the 3-D view factor and radiation transport code GOPHER, to model the flow of radiation up the channel past the first radiation baffle. We have concentrated our attention on the surface indicated by asterisks in Fig. 4. At this point the channel is still narrow but this surface does have some direct line-of-sight with the initial position of the wire array. We convolve the result of the view factor calculation with the predicted radiation flux from the RAVEN calculation and impose the resultant, time dependent, flux on this surface in another RAVEN, planar geometry, calculation. The predicted flux from the back of the load reaches a peak of 2.5×10^{12} W/m^2 during the temperature peak at 341.08 μs. During most of the calculation

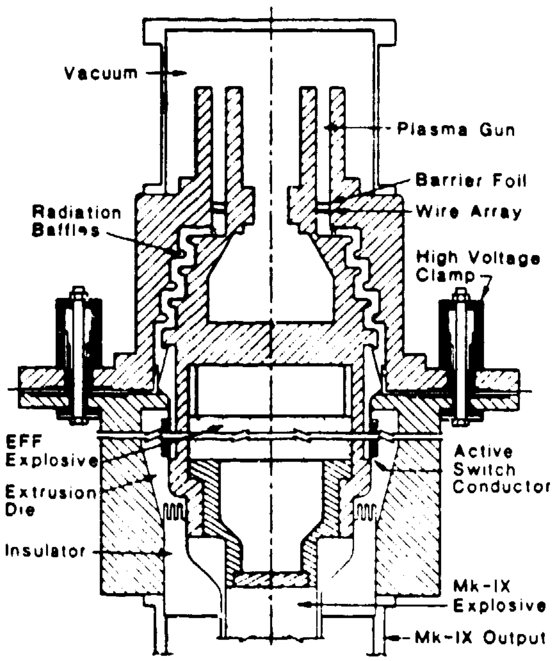

Fig. 4. Propose the dynamic load for future Trailmaster system. Surface modeled by the ablation calculation is marked by asterisks.

the flux is approximately 1×10^{12} W/m^2. We performed calculations assuming that the channel was clean, pure aluminum, and another with the aluminum coated with a 0.1 mm layer of a hydrocarbon. Far more ablation occurred in the hydrocarbon coated calculation and the time dependent positions of the zone boundaries are shown in Fig. 5. The ablated plasma moves about 0.8 cm, less than halfway across the channel. In addition, this is, almost certainly, a worst case calculation. In making our view factor calculation we used the initial position of the wire array throughout. By the end of the 4 μs shown in this calculation the wire array/plasma would have moved more than 6 cm down the channel. We conclude that radiation induced ablation is not a serious threat to cause channel closure in this design.

IV. Two-Dimensional MHD Calculations

Once specific designs have been determined for our work with the Pegasus capacitor bank and explosive generator systems, the 1-D calculations will be used to establish detailed initial conditions for the 2-D, Eulerian, MHD calculations. Prior to this we are using such 2-D calculations with generic initial conditions to examine the interaction between the switch plasma and the imploding load. We are particularly concerned that this interaction may impose perturbations on the load that could initiate a magnetically driven Rayleigh-Taylor instability. We note that the radiation pulses from the AFWL experiments have a FWHM of the order of 0.2 μs and full base width exceeding 0.7 μs.[1]

Figure 6 shows results of a 2-D calculation. In this calculation we are using a constant current drive of 10 MA. The initial radius of the load foil is 4 cm. In our 2-D work we start with the load somewhat expanded and in a plasma

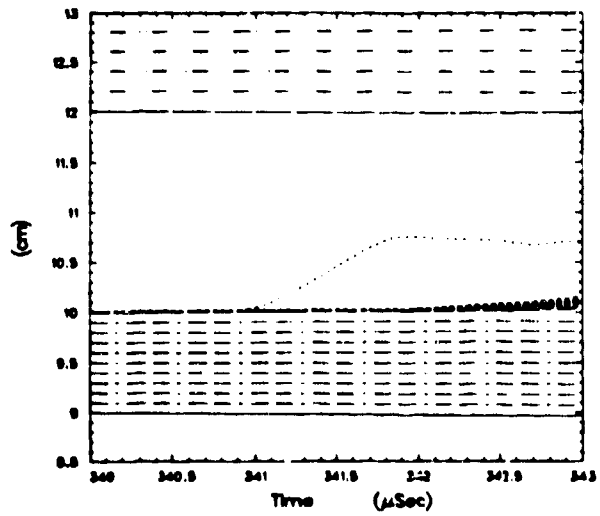

Fig. 5. One-dimensional, Lagrangian calculation of radiation induced ablation from the surface indicated in Fig. 4. The material being ablated is from a thin hydrocarbon layer.

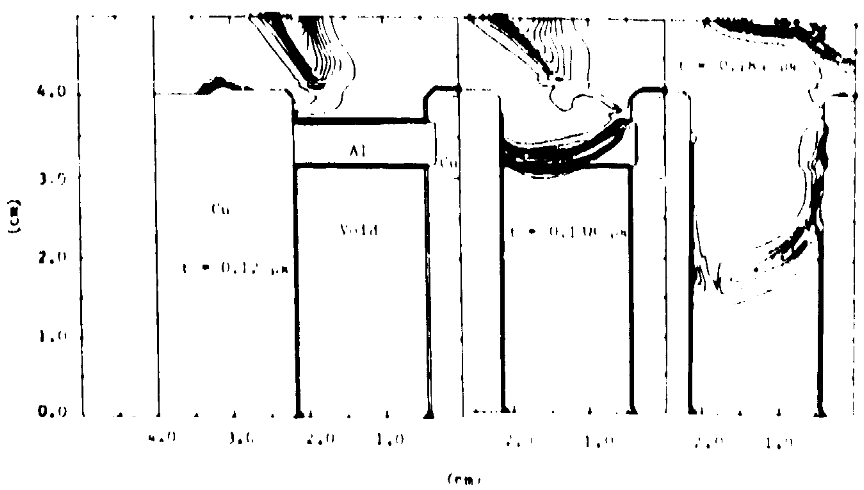

Fig. 6. This figure shows the interaction of the switch plasma and the imploding load at three times as calculated by a 2-D, Eulerian code. The switch plasma appears to initiate a Rayleigh-Taylor instability with a wavelength that is twice the height of the load.

The results shown in Fig. 6 clearly indicate that the interaction between switch plasma and the load can initialize an instability in the imploding load. This instability starts with a wavelength that is twice the height of the load. Therefore, this effect may be exacerbated by the catenary which tends to be present in our ultrathin foils and is not present in this calculation. These results also suggest, however, that it may be possible to ameliorate these problems by tailoring the load foils so that there is more mass near the region of first contact.

Acknowledgment

The authors wish to acknowledge the considerable assistance from and frequent valuable discussions with Dick Bartsch and Jim Goforth of Los Alamos, Mike Frese of Numerex Corporation of Albuquerque, and Peter Turchi of R&D Associates.

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